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PUBLIC HEALTH REPORTS.

UNITED STATES.

[Reports to the Surgeon-General, Public Health and Marine-Hospital Service.]

AN EXPERIMENTAL INVESTIGATION OF THE BITING OF MAN BY FLEAS TAKEN FROM RATS AND SQUIRRELS.

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The work of the Indian Plague Commission (Journal of Hygiene, Vol. VI, No. 4; Vol. VII, No. 3; Vol. VII, No. 6; Vol. VIII, No. 2) seems to have established beyond question that plague may be, and generally is, conveyed from rat to rat, and from rat to man, by fleas. The commission especially implicates the *Loemopsylla cheopis* (Roth.), the common rat flea of India, though it has shown that *Ceratophyllus fasciatus* (Bosc.) also is capable of conveying the infection.

The important rôle assigned to fleas in the spread of the disease makes it desirable to have accurate information as to whether certain species of fleas will bite man under experimental conditions.

This investigation of the subject was undertaken at the suggestion of Passed Asst. Surg. Rupert Blue, in charge of antiplague operations in San Francisco and vicinity, to whom we are indebted for facilities for carrying out the experiments.

The following brief review of the subject is taken almost entirely from papers in the Journal of Hygiene (Vol. VI, No. 4; Vol. VII, No. 3; Vol. VIII, No. 2):

In 1900 Galli Valerio (Centralbl. f. Bakt. Pt. 1, Vol. XXVII, p. 1) criticised the views of Simond, and Gauthier and Raybaud concerning the importance of fleas in the epidemic spread of plague purely on the ground that the rat fleas, *Ceratophyllus fasciatus*, Bosc., and *Ctenopsyllus musculi*, Duges, commonly found on rats in Europe, do not bite man. Gauthier and Raybaud (1902, Compt. Rend. Heb. de la Soc. de Bioll., IV, p. 1497; 1903, Révue d'Hygiene, XXV, p. 426) assert that 14 out of 16 fleas—identified by Rothschild as *L.* (*Pulex*) *cheopis*—taken from rats, bite men; and that furthermore some lived for several weeks feeding upon man's blood alone. Tidswell (1903, Report on the Second Outbreak of Plague in Sydney, p. 71) states that *P. pallidus* readily bites men when hungry and *C. fasciatus* occasionally. Tiraboschi (1903, Arch. f. Hygiene, Vol. XLVI, p. 251; 1904, Arch. d. Parasitol, Vol. VIII, p. 161) found the common flea upon rats in Italy to be *P. murinus*. He satisfied himself by numerous trials that this species, synonymous with *P. cheopis*, readily bites man. Verjbitski

(1904, Doctorate Thesis to the University of St. Petersburg, Journal of Hygiene, Vol. VIII, No. 2), in a highly important and brilliant contribution, concludes from a series of 40 experiments that rat fleas will not bite man. Doctor Verjbitski starved the fleas from 10 to 40 hours. The species used in his experiments was *C. musculi*, the common rat flea of central Russia. Liston (1905, Journ. Bombay Nat. Hist. Soc., Vol. XVI, p. 253) records that out of a collection of 30 fleas caught biting the occupants of a native "chawl" in Bombay, 14 were rat fleas, identified by Rothschild as *L. cheopis*.

The British Indian Plague Commission (Journ. of Hyg., 1907, Vol. VII, No. 3, p. 473) states in a special article on the biting of man by rat fleas that it has observed that if the fleas in the cage are abundant and if the natural food supply is limited, *L. cheopis* will feed on a man's hand even in the presence of a rat. In a series of 5 experiments the British Indian investigators were able to keep *L. cheopis* alive for nearly 4 weeks on a diet of human blood exclusively. The fleas kept under similar conditions, but without food, never survived longer than one week. The commission concludes that the rat flea *P. cheopis* is attracted by man under certain circumstances, readily biting and feeding on him.

Baker states (1904, Proc. U. S. Nat. Mus., Vol. XXVII, p. 368) that the mouse, rat, squirrel, mole, and shrew fleas have never been known to bite the human being, and he knows of no record of capture of such specimens on human hosts. Baker (ibid.) relates, however, that he has personally experienced the bites of rabbit fleas. Wherry (Journal of Infectious Diseases, Vol. V, No. 5, Dec. 18, 1908) states that hunters are frequently bitten by squirrel fleas, and in the Public Health Reports (Vol. XXIII, No. 48, Nov. 27, 1908) is reported an experiment demonstrating that squirrel fleas (*Ceratophyllus acutus* and *Hoplopsyllus anomalus*) will bite man under certain conditions.

This discordance of opinion concerning the biting of man by fleas from rodents is probably due to the use of various species of insects by different observers and by the use of dissimilar technique. The faunal conditions on the Pacific coast as regards the prevalence of fleas found on rats contrast notably with those of Europe, India, or Australia. The rat fleas predominating in Europe appear to be *C. fasciatus* and *Ct. musculi*, *L. cheopis* being relatively scarce. In India, *L. cheopis* is the common rat flea, *C. fasciatus* being rather rare. Reports from Australia indicate the great predominance of *L. cheopis*. So far as the region about San Francisco Bay is concerned, *C. fasciatus* predominates at all seasons of the year. *L. cheopis* is the next important rat flea in numbers; indeed, at certain seasons this species is found to outnumber *C. fasciatus* in some parts of San Francisco. The experiments with *C. fasciatus* (Journal of Hygiene, July, 1907, p. 414) showed conclusively that this species can convey plague from infected to healthy animals. This fact made our work with this insect especially interesting and, we believe, important.

Technique.—Fleas were collected from rats that were anesthetized with ether. A provisional identification of the species and sex of the fleas was made with a hand lens while they were under the influence of the ether. Each flea was then placed in a separate test tube, where it was kept until the termination of the experiment. A final identification of each insect was made with the low power of the microscope. It may be of interest to state that in every case the provisional identification was verified by the microscopical examination. This is in accord with our experience in general, which has shown that any of the common rat fleas may be readily identified with a hand lens or even by the naked eye. The fleas in the test tubes were applied to the hand or forearm of a healthy man from time to time as is shown in the following tables. The light was sometimes partially excluded by surrounding the test tube with the hand, but this was found to make no material difference in the results. In the interval between feedings the insects were kept at ordinary room temperature. Other methods of conducting the experiments, such as thrusting the hand into a jar containing a large number of fleas, would have allowed the use of a much larger number of insects, but would not have permitted the accuracy of observation we have attempted to attain in the present work.

We think it is a matter of sufficient importance to deserve mention that in not one instance was a flea observed to eject blood or feces per anum during the act of feeding, even when the meal was prolonged to nearly an hour; rarely, however, a flea would deposit feces on the skin, but never while actually feeding. This appears to be contrary to the observations of the Indian Plague Commission (Journal of Hygiene, Vol. VII, No. 3) and other investigators. The Indian Commission states that Simond (1898 Ann. de l'Inst. Pasteur, Vol. XII, p. 625) records the fact that while sucking, fleas were in the habit of discharging the contents of their intestine upon the skin in the neighborhood of the puncture. Zirolia (1902), in an article entitled "Der Pestbacillus im Organismus der Flohe" (Centralbl. f. Bakteriol. Orig., Vol. XXXI, p. 686), confirms Simond's statement that fleas while sucking frequently discharge the contents of their intestine. Concerning this matter we again take the liberty of citing Journal of Hygiene, July, 1907, Volume VII, No. 3, page 398: "We have already drawn attention to the habit which the flea possesses of squirting bright-red blood from the anus during the operation of sucking." And again in the same number (p. 418): "The flea while sucking has a habit of squirting blood per anum."

As is well known, the mechanism of biting by a flea consists essentially of two distinct operations; first, the insertion of the pricker and the mandibles and the injection of salivary secretion; and second, the drawing of blood from the host. It is quite conceivable that the first part of the procedure may occur without the second, but in these experiments we have often observed the abdomen of the insect to become distended and red, proving conclusively that blood was being withdrawn from the host. We noted that a flea would feed more regularly when the host was quiet than when he moved about.

The well known fact that flea bites are much more irritant to some persons than to others was well demonstrated in these experiments. In one of the subjects only a very small reddish macule resulted, even after prolonged feeding; in another an elevated red macule about 1 cm. in diameter appeared within a few hours after the biting, and the next day a distinct reddish papule was present which persisted for a week or longer and gave rise to marked itching.

Another interesting point was that sometimes a flea would refuse to feed on one observer, but would feed at once when transferred to the other.

We have found by actual trial that a considerable percentage of both *L. cheopis* and *C. fasciatus*, with or without previous starvation, will attack man when given an opportunity to choose between man and a rat.

Legend.—F, female; M, male; O indicates that the flea was not applied; +, fed less than 5 minutes; ++, fed vigorously more than 5 minutes; —, did not feed after 5 minutes' application; S, fed slightly; E, escaped; D, dead.

Rat fleas (ceratophyllus fasciatus).

[Fleas collected from *M. norvegicus*, November 16, 1908.]

Number of specimen	1.	2.	3.	4.
Sex	M.	F.	F.	F.
1908				
November 16	O.	O.	O.	O.
November 17 (2d day)	—	+ +	O.	+ +
November 18 (3d day)	—	+ +	+	+
November 19 (4th day)	D.	+	—	D.
November 21 (6th day)	......	—	D.	......
November 24 (9th day)	......	D.	......	......

[Removed from host *M. norvegicus*, January 8, 1909.]

Number of specimen	1.	2.	3.
Sex	F.	M.	M.
Three hours after removal from host	S.	S.	S.
January 9	+ +	+	S.
January 13	D.	D.	D.

[Fleas removed from host *M. norvegicus* January 9, 1909.]

									Controls.			
Number of specimen	1.	2.	3.	4.	5.	6.	7.	8.	A.	B.	C.	D.
Sex	F.	F.	F.	F.	F.	F.	F.	F.	F.	F.	F.	F.
4 hours after collecting	S.	—	+	+	O.	O.	O.	O.	O.	O.	O.	O.
Jan. 10 (2d day)	—	—	—	S.	O.	O.	O.	O.	O.	O.	O.	O.
Jan. 11 (3d day)	+	—	—	—	+	+	+	+	D.	O.	O.	D.
Jan. 12 (4th day)	—	S.	+ +	+ +	O.	O.	O.	O.	...	O.	O.	...
Jan. 13 (5th day)	+	S.	S.	+	+ +	+ +	+	+	...	D.	D.	...
Jan. 14 (6th day)	S.	S.	+	+	O.	O.	O.	O.	...	...	...	...
Jan. 15 (7th day)	S.	—	+	+	+	+ +	+ +	+ +	...	...	...	...
Jan. 17 (9th day)	+	+ +	+ +	+	+ +	+ +	+ +	S.	...	...	...	...
Jan. 19 (11th day)	+ +	+ +	+ +	+ +	O.	O.	O.	O.	...	...	...	...
Jan. 20 (12th day)	D.	—	E.	+ +	+	+ +	+ +	D.	...	...	...	...
Jan. 21 (13th day)	......	+ +	......	+ +	O.	O.	O.	......	...	...	...	...
Jan. 23 (15th day)	......	+ +	......	+ +	+ +	+ +	+ +	......	...	...	...	...
Jan. 24 (16th day)	......	—	......	+ +	+	+ +	+	......	...	...	...	...
Jan. 25 (17th day)	......	D.	......	......	......	D.	......	......	...	...	...	...

[Fleas removed from host *M. norvegicus* December 22, 1908.]

Number of specimen	1.	2.	3.	4.	5.	6.	7.	8.	9.
Sex	F.	F.	M.	F.	F.	F.	M.	M.	M.
1 hour after removal from host	O.	O.	O.	—	—	+	+	+	—
1908.									
Dec. 23 (2d day)	O.	O.	O.	—	S.	S.	S.	+	+
Dec. 25 (4th day)	+	S.	S.	+	+	+	+	S.	—
Dec. 26 (5th day)	—	S.	+	+	S.	+	+	D.	—
Dec. 27 (6th day)	S.	—	S.	+	+	+	S.	......	+
Dec. 28 (7th day)	S.	+ +	S.	S.	+	+ +	+ +	......	+ +
Dec. 29 (8th day)	+ +	+ +	+	+ +	+	+ +	+	......	+ +
Dec. 31 (10th day)	S.	+	S.	+ +	+	+ +	+ +	......	+
1909.									
Jan. 2 (12th day)	+	+	+	+	E.	+	+	......	S.
Jan. 5 (15th day)	S.	+	E.	+	......	+	+ +	......	D.
Jan. 7 (17th day)	+	+	......	—	......	D.	D.	......	......
Jan. 9 (19th day)	+	+	......	+	......	......	......	......	......
Jan. 13 (23d day)	+ +	+ +	......	+ +	......	......	......	......	......
Jan. 14 (24th day)	S.	+ +	......	+	......	......	......	......	......
Jan. 15 (25th day)	S.	+ +	......	+ +	......	......	......	......	......
Jan. 17 (27th day)	+	+	......	+ +	......	......	......	......	......
Jan. 18 (28th day)	+	+	......	+	......	......	......	......	......
Jan. 19 (29th day)	+	+	......	+ +	......	......	......	......	......
Jan. 20 (30th day)	+	S.	......	+	......	......	......	......	......
Jan. 21 (31st day)	S.	+	......	+	......	......	......	......	......
Jan. 23 (33d day)	+ +	+ +	......	+ +	......	......	......	......	......
Jan. 24 (34th day)	+	+ +	......	+	......	......	......	......	......
Jan. 25 (35th day)	+ +	+	......	+ +	......	......	......	......	......

Four controls unfed (1 F., 3 M.) were found dead on December 27.

On account of the prevalence of *C. fasciatus* on rats in this vicinity we attach special importance to the experiments conducted with this species. The table demonstrates that this flea, which is taxonomically not at all closely related to the ordinary flea found on man (*Pulex irritans*), will feed readily on man and may be kept alive for as many as 35 days on man's blood alone; controls (unfed) all dying within 5 days. In one experiment 3 out of 6 fed on man when applied one hour after removal from the rat.

Loemopsylla cheopis.

[Fleas collected from *M. norvegicus* on November 16, 1908.]

Number of specimen	1.	2.	3.	4.
Sex	M.	M.	M.	F.
Nov. 17 (2d day)	—	—	O.	S.
Nov. 18 (3d day)	+	+ +	S.	S.
Nov. 19 (4th day)	—	+ +	+	—
Nov. 21 (6th day)	—	—	D.	D.
Nov. 24 (9th day)	D.	D.	......	......

[Removed from *M. norvegicus* December 31, 1908.]

									Controls.						
Number of specimens	1.	2.	3.	4.	5.	6.	7.	8.	A.	B.	C.	D.	E.	F.	G.
Sex	M.	F.	M.	M.	M.	M.	M.	F.	M.	F.	F.	M.	F.	M.	F.
1909.															
Jan. 1 (2d day)	—	—	+		—	S.	S.	S.	O.	O.	O.	O.	O.	O.	O.
Jan. 2 (3d day)	+	—	++	—	—	S.	S.	—	D.	O.	O.	D.	O.	O.	...
Jan. 4 (5th day)	+ +	—	+	+	S.	+	D.	—	D.	D.	D.	D.	O.	D.	D.
Jan. 6 (7th day)	+	+ +	+	+ +	+ +	+ +	...	+	...	...	...	...	D.	...	...
Jan. 7 (8th day)	—	—	+	S.	+	S.	...	+	...	...	...	...	...	...	...
Jan. 8 (9th day)	—	—	+	S.	S.	—	...	—	...	...	...	...	...	...	...
Jan. 9 (10th day)	+	S.	S.	+	+	+ +	...	S.	...	...	...	...	...	...	...
Jan. 11 (12th day)	+	+ +	D.	+	S.	+ +	...	+ +	...	...	...	...	...	...	...
Jan. 14 (15th day)	S.	S.	......	E.	D.	D.	...	+ +	...	...	...	...	...	...	...
Jan. 15 (16th day)	E.	+ +	......	......	......	......	...	+	...	...	...	...	...	...	...
Jan. 17 (18th day)	......	+ +	......	......	......	......	...	—	...	...	...	...	...	...	...
Jan. 19 (20th day)	......	S.	......	......	......	......	...	+ +	...	...	...	...	...	...	...
Jan. 20 (21st day)	......	+ +	......	......	......	......	...	S.	...	...	...	...	...	...	...
Jan. 21 (22d day)	......	S.	......	......	......	......	...	—	...	...	...	...	...	...	...
Jan. 23 (24th day)	......	S.	......	......	......	......	...	+ +	...	...	...	...	...	...	...
Jan. 24 (25th day)	......	S.	......	......	......	......	...	+ +	...	...	...	...	...	...	...

Our experiments confirm the experience of the Indian plague commission that *L. cheopis* feeds readily on man and that it may be kept alive for many days on human blood alone.

Ctenopsyllus musculi.

[Removed from host *M. rattus* January 14, 1909.]

Number of specimen	1.	2.	3.	4.	5.
Sex	F.	F.	F.	M.	F.
1 hour after removal from host	—	—	—	—	S.
Jan. 15 (2d day)	+ +	D.	S.	D.	S.
Jan. 16 (3d day)	S.	......	D.	......	D.
Jan. 17 (4th day)	D.	......	......	......	......

[Removed from host *M. norvegicus*, January 19, 1909.]

Number of specimen	1.	2.
Sex	F.	M.
6 hours after removal from host	+	+
Jan. 20 (2d day)	D.	D.

Ctenopsyllus musculi—Continued.

[Removed from host *M. norvegicus*, January 18, 1909.]

									Controls.		
Number of specimen	1.	2.	3.	4.	5.	6.	7.	8.	A.	B.	C.
Sex	F.	F.	M.	M.	M.	F.	M.	M.	F.	F.	F.
5 hours after removal from host	–	S.	+	S.	–	+	S.	–	O.	O.	O.
Jan. 19 (2d day)	+ +	+ +	+ +	D.	S.	D.	–	+	D.	D.	D.
Jan. 20 (3d day)	+ +	+	D.	...	D.	...	D.	D.	...	...	...
Jan. 21 (4th day)	+ +	D.	...	...	...	...	...	...	...	...	...
Jan. 22 (5th day)	D.	...	...	...	...	...	...	...	...	...	...

The experiments with *Ct. musculi* have not been as extensive as we wished to make them, because we have found it difficult to procure this species of flea alive, as they are relatively scarce in San Francisco. The table demonstrates that some of these fleas will bite man soon after taken from their normal host, and a considerable percentage of those that survived fed readily on man on the second and third days after their removal from the rat.

Squirrel fleas (*Hoplopsyllus anomalus, Ceratophyllus acutus*).

[Removed from *host Citellus beecheyi*, December 28, 1908.—1, 2, 3, A, *H. anomalus;* 4, 5, 6, 7, 8, B, C, *C. acutus.*]

									Controls.		
Number of specimen	1.	2.	3.	4.	5.	6.	7.	8.	A.	B.	C.
Sex	F.	F.	M.	F.	F.	M.	M.	F.	M.	F.	M.
Dec. 28 (1st day)	S.	–	+	S.	S.	+	–	+	O.	O.	O.
Dec. 29 (2d day)	+	–	+ +	+ +	+	+ +	S.	+ +	O.	O.	D.
Dec. 31 (4th day)	+	S.	+	+	D.	+	S.	+	D.	O.	...
Jan. 1 (5th day)	+	S.	+	D.	...	+ +	+	+	...	D.	...
Jan. 2 (6th day)	+	+ +	+ +	...	...	+	+	+	...	...	...
Jan. 4 (8th day)	D.	+ +	+ +	...	...	+	+	+	...	...	...
Jan. 7 (11th day)	...	D.	D.	...	...	D.	D.	+ +	...	...	...
Jan. 10 (14th day)	...	...	...	...	...	...	...	+	...	...	...
Jan. 13 (17th day)	...	...	...	...	...	...	...	+ +	...	...	...
Jan. 14 (18th day)	...	...	...	...	...	...	...	+ +	...	...	...
Jan. 16 (20th day)	...	...	...	...	...	...	...	+ +	...	...	...
Jan. 17 (21st day)	...	...	...	...	...	...	...	+ +	...	...	...
Jan. 18 (22d day)	...	...	...	...	...	...	...	S.	...	...	...
Jan. 20 (24th day)	...	...	...	...	...	...	...	+ +	...	...	...
Jan. 21 (25th day)	...	...	...	...	...	...	...	+	...	...	...
Jan. 22 (26th day)	...	...	...	...	...	...	...	+ +	...	...	...
Jan. 23 (27th day)	...	...	...	...	...	...	...	+ +	...	...	...
Jan. 24 (28th day)	...	...	...	...	...	...	...	+ +	...	...	...

The one experiment with the common ground squirrel fleas of California shows that these insects bite man readily, and that they may be kept alive on man's blood for at least 28 days.

Summary.—A large majority of the two common species of fleas found on rats in San Francisco, *Loemopsylla cheopis* (Roth) and *Ceratophyllus fasciatus* (Bosc), will bite man under the conditions of these experiments. *Ceratophyllus fasciatus* usually feeds very vigorously on man's blood, and it was kept alive on this diet for 35 days.

Most of the *Ctenopsyllus musculi* died early in captivity, but it is shown that they will at times bite man.

Squirrel fleas, *H. anomalus* and *C. acutus*, feed readily on man's blood.

Starvation does not appear to play any very important rôle in determining whether a flea will bite or not. Some of these tables give the impression that the fleas become accustomed to the blood of a new host.